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SOLVENT CHEMICAL INVENTORY OF THE NEWARK AFB BUILDING 4 FACILITY

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Emissions of organic solvents are the subject of progressively stricter environmental quality regulations. Solvents used to clean electronic components and metal surfaces are a major source of USAF emissions of volatile organic compounds (VOCs) to the atmosphere. Wherever possible, replacement of the organic source of emissions by water-based materials will emerge as the long-term remedy; during the interim, existing solvent-based operations must change to stay in compliance with ambient air quality and safety requirements.

During this study, data (solvent procurement, storage, distribution, usage, recovery, and disposal) were collected from purchase records, monthly issue reports, an annual inventory report, an earlier room-by-room solvent usage survey, and individual interviews with site personnel. Correlations between issue, inventory, and usage calculations, and analysis of sensitivity to estimation errors indicate reliability of calculated values. Material balance calculations show annual losses to the atmosphere of 555,000 pounds of 1,1,2-trichloro-1,2,2-trifluoroethane (freon) and 110,000 pounds of 1,1,1-trichloroethane.

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EXECUTIVE SUMMARY

Solvent Chemical Inventory of the Newark AFB Building 4 Facility

A. OBJECTIVE:

The objective of this effort was to identify and quantify the organic chemicals issued, used, recovered, and disposed of during a year of operations in Building 4, Newark AFB OH, and, by performing mass balance calculations with these data, to estimate the annual loss to the atmosphere of volatile organic compounds (VOCs) and chlorofluorocarbons (freons) from operations in Building 4.

B. BACKGROUND:

Under the Clean Air Act and various state and local laws, organic solvents and coating compounds used in routine maintenance procedures are sources of volatile emissions that are subject to regulation as VOCs and as hazardous air pollutants. Air Force installations are experiencing increasing pressure from local agencies to decrease solvent emissions. A rapidly developing focus of regulatory pressure is chlorofluorocarbons, including 1,1,2-trichloro-1,2,2-trifluoroethane (freon), and 1,1,1-trichloroethane (TCA), which have been demonstrated to contribute both to ozone depletion and to global climate changes. During the interval while suitable replacements are being developed to allow effectively complete removal of freons from service, the Air Force is actively seeking ways to decrease rates of emission from essential sources.

C. SCOPE:

During this study, solvent procurement, storage, distribution, usage, recovery, and disposal data were collected from base sources: purchase records, monthly issue reports, an annual inventory report, an earlier room-by-room survey of solvent usage, and individual interviews with site personnel. Correlations between issue, inventory, and usage calculations, and sensitivity analysis of the effect of errors of estimation indicate good reliability of the values so generated. Material balance calculations were performed, which showed annual losses to the atmosphere of 555,000 pounds of freon and 110,000 pounds of TCA.

D. METHODOLOGY:

Recorded information was supplied by Newark AFB personnel. Other information was provided by site personnel during individual interviews. Emissions data were calculated as the discrepancy in mass balance (quantity of solvent procured less the quantity of solvent disposed). Parallel calculations of common quantities and sensitivity analyses of the calculations of the largest quantities were performed to demonstrate the reliability of the numbers generated.

E. TEST DESCRIPTION:

No experimental measurements were taken during this study.

F. RESULTS:

Discrepancies in mass balance calculations indicate emissions during the 1-year period of the study of 555,000 pounds of freon and 110,000 pounds of TCA. Correlation of parallel calculations of common values and sensitivity analyses indicate reliability of input data and of calculated values.

G. CONCLUSIONS:

Significant decreases in solvent loss rates from operations in Building 4 can be attained cost effectively by changes to the ventilation system and maintenance schedule.

H. RECOMMENDATIONS:

Ducting all of the work areas using TCA and freon to the CA recovery system and stepping up the regeneration schedule for the CA system were suggested as initial modifications. Detailed recommendations are included in ESL-TR-89-27.

PREFACE

This report was prepared by Acurex Corporation, Mountain View, California, under Environmental Protection Agency (EPA) Contract No. 68-02-4285, funded by the Air Force Engineering and Services Center, Engineering and Services Laboratory (AFESC/RDVS), Tyndall Air Force Base, Florida 32403-6001.

This report summarizes work done between April 1987 and May 1988, under the direction of Dr. Dean Wolbach, Acurex Corporation. The EPA work assignment officer was Charles H. Darvin, Air and Energy Engineering Research Laboratory, Research Triangle Park, North Carolina. Mr. Surendra B. Joshi and Dr. Joseph D. Wander were the Air Force project officers for this contract.

Support and assistance provided by personnel of the Newark AFB Aerospace Guidance and Metrology Center Physical Science Laboratory and the Maintenance Department (MA) is gratefully acknowledged.

This report has been reviewed by the Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for public release.

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GLOSSARY OF TERMS

Accountable Freon	Quantity of freon lost (by evaporation or as manifested waste) that could be accounted for.
Ambient room air	Air in process room housing a specific work station.
CA	Carbon adsorption
Chemical Inventory Survey (CIS)	Compilation of data showing where and how solvent is used at a facility
Distillation system	Operations at Newark AFB relating specifically to the distillation equipment and its usage.
Freon	A common name for chloroperfluorocarbons. In this document, 1,1,2-trichloro-1,2,2-trifluorethane (Freon™ 113).
Lost freon	Total quantity of freon that was lost at Newark AFB, either via evaporation or as manifested waste.
Manifested waste	Solvents that are drummed and either sold to a recycler or shipped to a treatment facility as hazardous waste.
Mass balance	The process of reconciling the quantity of a substance used in a process with the quantities recovered and lost by evaporation.
Process operation	Operations at Newark AFB relating specifically to the cleaning and maintenance of electronic parts (e.g., flushing, spraying, degreasing).
PSL	Newark AFB Aerospace Guidance and Meteorology Center Physical Science Laboratory
TCA	1,1,1-Trichloroethane.
TFLPC	Total Freon Lost Percent Closure - ratio of accounted losses from process and distillation system operations to identified total losses (total purchased minus manifested waste).
TPPC	Total Throughput Percent Closure - ratio of estimated throughput from worker surveys, usage rate calculations, and PSL reports to expected total throughput from distillation system operation records and purchase data.
Unaccountable freon	Quantity of freon lost that was not accounted for.
Unrecovered freon	Quantity of freon lost by evaporation at Newark AFB during the time period studied.

SECTION I

INTRODUCTION

A. OBJECTIVE

The objective of this project was to develop a chemical inventory profile for Building 4, Newark AFB, Ohio, and to determine the magnitude and location of the primary solvent emissions. The principal processes included in this study are electronic equipment cleaning operations.

B. BACKGROUND

Newark AFB uses a number of solvents to clean and maintain electronic equipment. The solvent used most often in these applications is 1,1,2-trichloro-1,2,2 trifluoroethane, a chlorofluorocarbon (CFC) commonly known by the DuPont Company trademark, FreonT 113 (hereafter referred to as freon). Another commonly used solvent is 1,1,1-trichloroethane (hereafter referred to as TCA). Scientific evidence suggests that CFC emissions may contribute to depletion of the protective ozone layer surrounding the earth's atmosphere. For this reason, various federal agencies are pressuring DOD facilities to decrease CFC emissions.

The Newark AFB facility uses large quantities of freon and TCA, much of which it loses to the atmosphere every year. Several steps have been taken to decrease the quantity of freon lost at Newark AFB. For example, continuously operated distillation equipment is used to purify recovered liquid freon for reuse. However, military specifications require that most processes use ultra-pure solvent, so only freon that is not significantly contaminated may be recycled. The remainder is sold to an offsite waste-handling facility. The recovery of solvent vapors emitted from clean-room sources has also been attempted at the Newark AFB facility. There are two carbon adsorption (CA) recovery systems in place; however, the recovery efficiencies of these units have been marginal.

C. SITE DESCRIPTION

The facility of interest at Newark AFB is Building 4, in which gyroscopes and mechanical components of inertial guidance systems are cleaned and repaired. The facility consists of a large, three-level building that houses smaller buildings or rooms. Cleaning and repair work are performed on the first floor, which consists of more than 540,000 square feet of enclosed space. A location map and first-floor plan are shown in Figures 1 and 2.

The facility contains several individual solvent emission point sources, about half of which are clean rooms. Clean rooms consist of one or more smaller rooms to which filtered air is supplied at constant temperature and humidity. Within these various operating areas there may be solvent spray booths, flush stations, vapor degreasers, ultrasonic cleaners, or benchtop brushing/wiping work areas.

To control solvent emissions and recover freon, Building 4 is equipped with two carbon adsorption (CA) systems. Five of the ten clean rooms and four of the nine other cleaning areas/rooms are vented to these beds. In addition

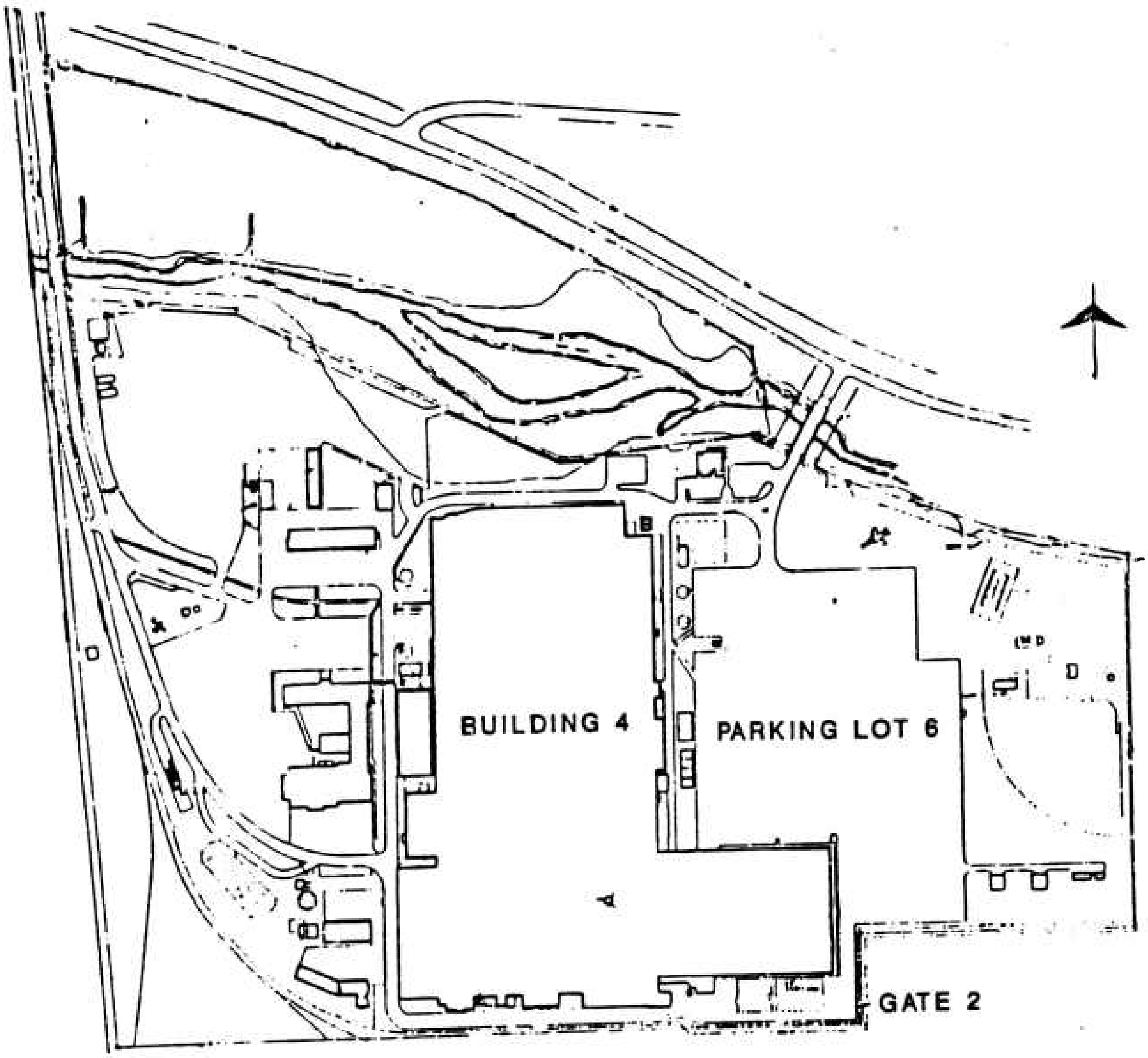


Figure 1. Location Map, Newark Air Force Base, Ohio

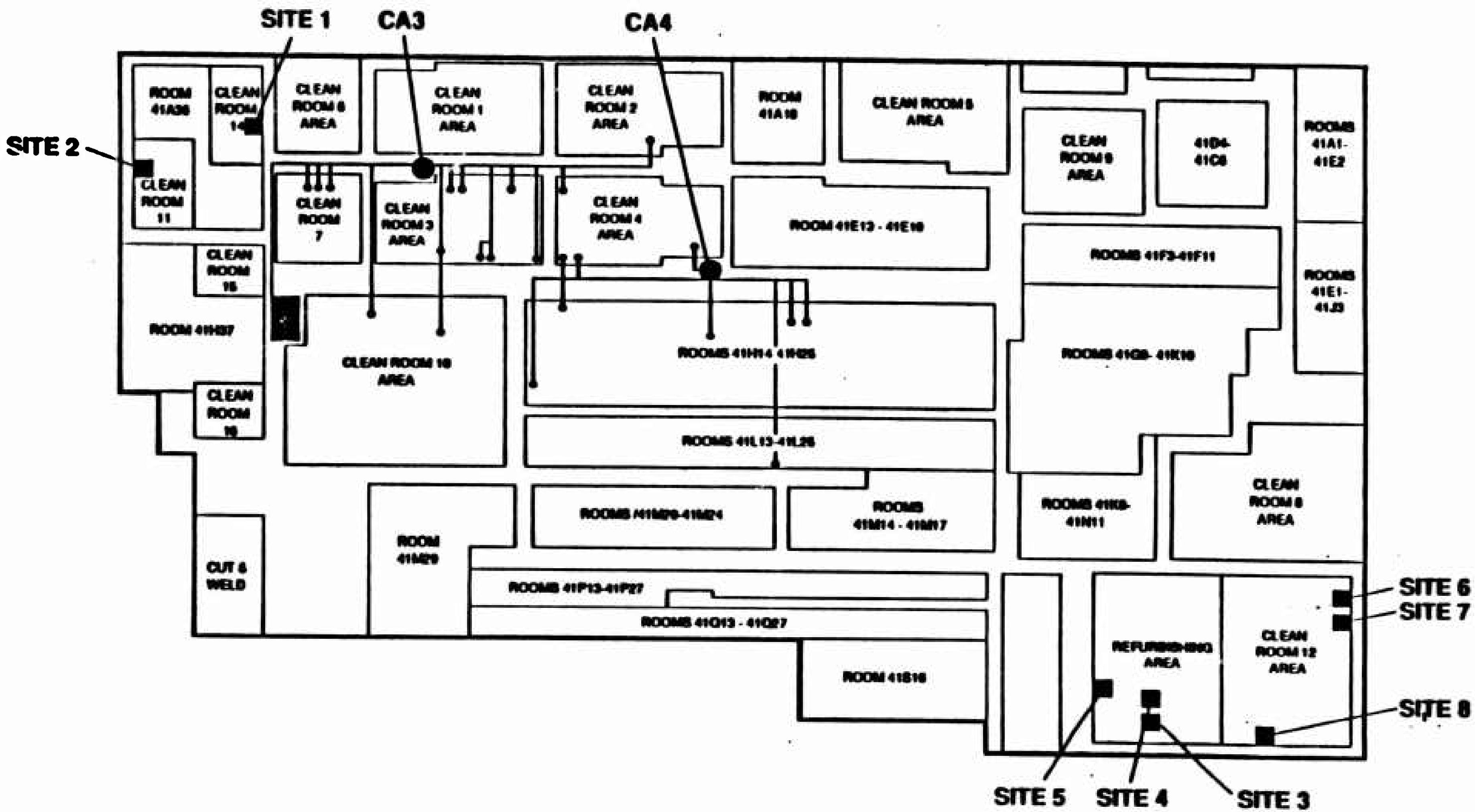


Figure 2. Building 4 First Floor Plan, Newark Air Force Base

to the CA vapor recovery system, a continuously operated distillation system is used to purify recovered liquid freon for reuse. The liquid freon and other solvents are collected from the CA systems and from containers located outside the areas of use. At some work stations, liquid waste solvents flow through drain pipes directly from the work area to the still.

D. APPROACH

The project was conducted in two related steps. A chemical inventory survey (CIS) was performed to determine the types and quantities of solvents used in Building 4 and the quantities manifested for disposal. The CIS results provide a "snapshot" of the types and quantities of materials used at Newark. Step two consisted of a detailed solvent mass balance designed to identify where and how freon and TCA are used in the facility, and the characterization of solvent recovery system operations. The goal of the mass balance was to determine the usage rate and the fate of freon and TCA. In addition, the respective operations of the freon distillation and carbon adsorption (CA) systems were analyzed to determine their effect on solvent management.

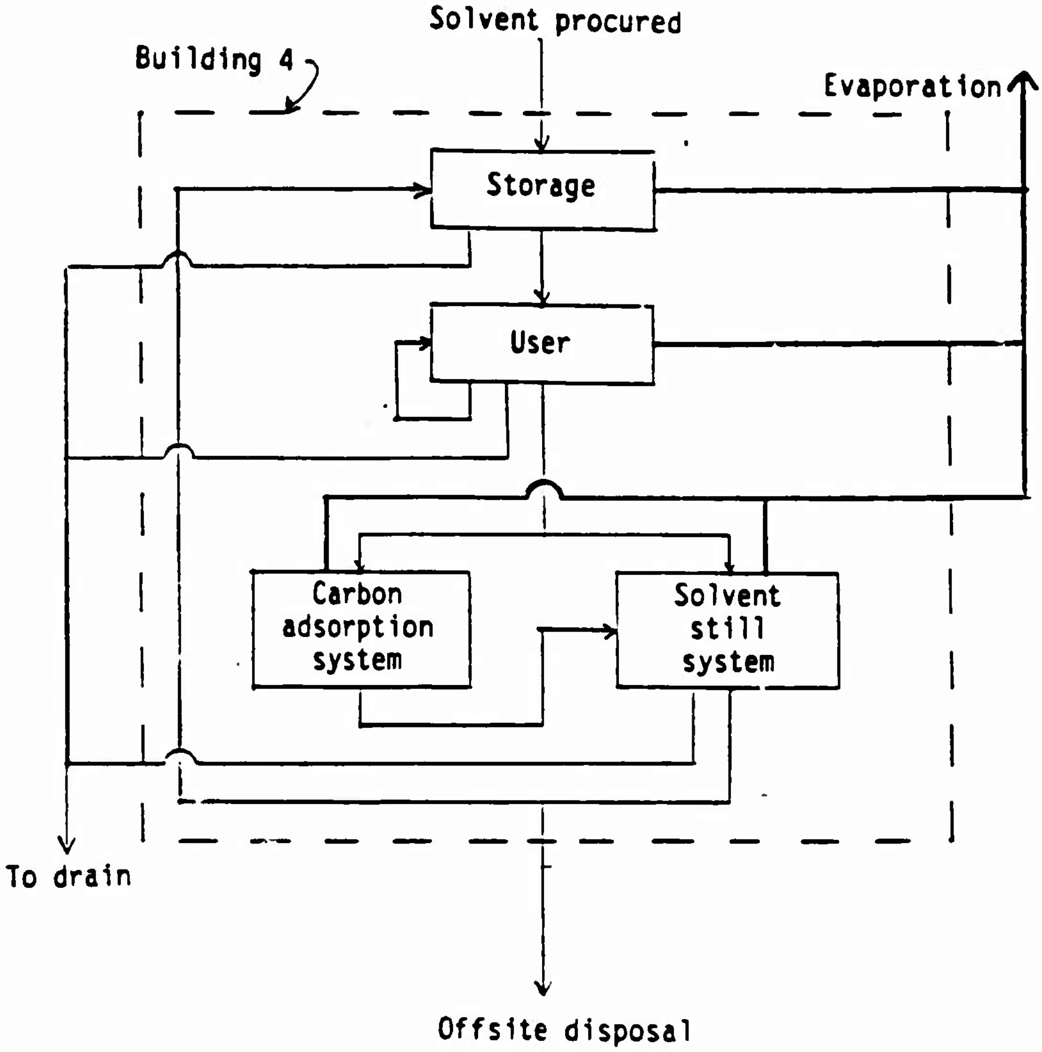
1. Chemical Inventory Survey

The CIS was performed by analyzing solvent purchase data, M15 monthly hazardous materials issue reports, and the N82 12-month inventory report. The M15 monthly hazardous materials issue reports provide data specifying the types and quantities of solvents used in different areas. The N82 12-month inventory report consists of warehouse issue and inventory data. In addition, information gathered for the solvent mass balance during a room-by-room survey of solvent usage was incorporated in the CIS analysis.

2. Solvent Mass Balance

The solvent mass balance task was completed through a series of data-gathering and analysis steps focusing on freon and TCA usage. The general approach was to determine the amount of solvent used by the facility during a typical one-year period and reconcile this quantity with the amount of solvent recycled, the estimated amount of solvent lost by evaporation, and the amount manifested for offsite disposal during this period. The general approach taken for the mass balance is diagrammed in Figure 3.

Information was first gathered on the overall freon and TCA usage rates at Newark AFB. Next, specific usage and loss rates were identified through a mass balance around various rooms or areas within Building 4, followed by balances around individual pieces of equipment where possible. Operating characteristics for the various pieces of cleaning equipment were determined through detailed interviews with the operators in each room in which freon and TCA are used. This information was supplemented by the Newark AFB Aerospace Guidance and Metrology Center Physical Science Laboratory (PSL) reports, which consist of environmental assessments of specific rooms. These assessments describe the operating procedures and venting arrangements of the rooms in question, as well as the types of equipment present. Solvent recovery and recycle data were determined from the daily records of the solvent distillation system and staff notes on CA system operations. Engineering evaluations and calculations were used to estimate any additional losses for which documented data were not available. Newark personnel from the Maintenance Department (MA) and the PSL assisted Acurex staff in gathering solvent usage data.



General Equation:

Solvent(t) in + _solvent(t) stored = solvent(t) manifested for disposal

+ solvent(t) to drain

+ solvent(t) evaporated

Solvent(t) = quantity of solvent passing through specified process during time increment <u>t</u>

Figure 3. General Approach Taken for Mass Balance

SECTION II

DATA SOURCES, RELIABILITY, AND ANALYTICAL PROCEDURES

Data sources for the chemical inventory survey (CIS) and the mass balance, although complementary, are discussed separately. Table 1 summarizes all sources of data used in this report.

A. CHEMICAL INVENTORY SURVEY

1. Chemical Inventory Survey Data Collected

The data used in the CIS came from a variety of sources. For the solvents freon, TCA, isopropyl alcohol (IPA), acetone, toluene, and methanol, data from purchase logs were used. The logs detail the date of purchase, quantity, and purity of the solvent, as determined analytically by the Newark AFB Chemistry Laboratory. The physical characteristics of freon and TCA (density, vapor pressure, vapor density) were available from Material Safety Data Sheets (MSDSs).

A compilation of issue data from 19 April 1987 to 19 April 1988 was made using the N82 12-month inventory report. This computer printout, The Monthly HHI Review N82, lists, by stock number, the quantity of each solvent remaining in the warehouse on a certain date (in this case 19 April 1988) and the total amount issued during the preceding 12 months.

Monthly solvent issue data were available from the M15 Hazardous Materials Usage Reports for the months of November and December 1987, and January, March, April, and May 1988. All solvents, except freon, issued for use in Newark AFB maintenance activities are listed in this report. This report details the user's room number, name of activity, office symbol, phone number, and the quantity and type of solvent issued.

Disposal data were available for waste solvents from the various operations and for solvent from the distillation system that did not meet the required standards of purity. Before these wastes were disposed offsite, each drum was analyzed by the chemistry laboratory to determine the percent present of freon, TCA, acetone, IPA, toluene, and water. This information is available on a computer printout, sorted by date, work order number, and destination of the sampled drum.

The information gathered for the solvent mass balance was then incorporated into the CIS. The survey is discussed in Section III.

Conversations with Newark AFB personnel revealed that detailed monthly and annual records of solvent quantities purchased and issued are kept on computer tape, but that they are not readily available. A formal Air Force request must be made to obtain the information and a computer program must be generated keying on the data of interest. This procedure would have required two or more months to complete, after approval by Air Force management. For this reason, data were not obtained from this source.

TABLE 1. SOURCES OF DATA

Information Collected	Resource
Solvent purchase data	Monthly Hazardous Material Issue Report
Warehouse inventory data	Monthly HHI Review N82 Report
Waste shipped offsite	Waste manifest log book
Liquid losses (i.e., spills)	Hazardous Material Incidents/Spills Report
Solvent distillation rates	Distillation operation log book
Solvent characteristics	Material Safety Data Sheet
Cleaning and process room operations	Room-by-room solvent usage survey

2. Assessment of Chemical Inventory Survey Data Quality

The information gathered from purchase logs (including purity analyses) is considered accurate. The limited data available in the N82 report printout are also considered accurate; however, this source does not include the amount of solvent in inventory at the beginning of the period. For this reason, an accurate comparison of purchase data against inventory and issue data is not possible, and, indeed, when the data for TCA purchased during the April to April period are compared with the warehouse TCA balance and issue data from the N82 inventory report, it appears that the issue data may have understated (or purchase data overstated) the actual amount by about 6 drums.

TCA IN - TCA OUT	=	CHANGE IN STORAGE BALANCE
13,900 gallons - 11,346 gallons	=	1,744 gallons
Actual Storage Balance	=	26 drums (1,430 gallons)

Assuming that the initial storage balance was 0, this implies that at least 314 gallons (1,744-1,430 = 314 gallons or 5.7 drums) are not accounted for. However, this discrepancy represents only 2.4 percent of the total quantity of TCA purchased for the year.

The data concerning the composition of wastes manifested for disposal are considered very accurate. However, there are two factors that could have an effect on the estimate of total solvent mass disposed offsite. One is that the computer list detailing waste compositions may be incomplete. The other is that the volume of waste assumed in each drum manifested for disposal is an estimate. The incomplete computer list is not considered a significant source of error because of the check points involved in handling hazardous waste (e.g., the hazardous waste manifest). For example, the assumption of an

average of 50 gallons per manifested drum may be in error. However, as the 55-gallon waste drums used at Newark AFB are usually filled to between 45 and 55 gallons when shipped offsite, the potential for error is minor.

3. Chemical Inventory Survey Analytical Procedures

Straightforward analytical procedures were applied to the CIS data. Purchase, issue, and disposal data for the solvents used at Newark AFB were compiled and are presented in one table. Monthly purchase and manifest data for freon and TCA were plotted versus time. Although it would have been preferable to use issue data, these were unavailable for freon. Therefore, purchase data were used to calculate freon usage rates (see Section III.A). One-month time increments were used to simplify data handling. All solvent purchases and disposal transactions during each month were assumed to occur on the 30th of the month. A multiple-regression analysis was used to determine the best straight line through the data points. The resulting slopes represent the average monthly solvent purchase and disposal rates. The slope of the plotted purchase data was then divided by the slope of the plotted disposal data to determine the ratio of solvent purchased to waste disposal, which is shown on the plots. The reciprocal of this factor is the average fraction of purchased solvent that is eventually manifested as waste.

4. Reliability of Chemical Inventory Survey Results

The foregoing discussion indicates that the CIS results provide an accurate profile of the types and quantities of solvents used at Newark AFB. If solvents were omitted from this inventory, it is because they are used in negligible quantities. The accuracy of the issue data is difficult to ascertain because they come from two sources, one of which is incomplete. As a consequence, the purchase data were relied on to determine quantities, and the issue data were used to determine solvent types and points of use.

B. FREON AND TCA MASS BALANCE

1. Mass Balance Data Collected

The data sources utilized for the freon and TCA mass balance can be separated into two types - written information pertaining to quantities purchased, recycled and manifested as hazardous waste, and verbal and/or written information pertaining to solvent usage and loss rates in different areas within the facility. The purchase and waste manifest data are discussed in Section III. These data were augmented with data from the waste manifests, solvent usage surveys, and solvent handling systems, i.e., the freon distillation system and the carbon adsorption (CA) units. In addition, data on solvent concentrations in the facility wastewater were used.

The sources of data concerning solvent handling within the facility follow:

- Distillation System. The distillation operations daily notebook provided information concerning the quantity of freon that was recycled. This notebook recorded the daily output of the quality control (QC) tank, which is the

controlling tank for all of the recycled freon. The amount of freon purified by the distillation system was determined from the total quantity of solvent that passed through the quality control tank. All recycled freon passes through this 300-gallon tank, which was typically filled twice each day to an assumed volume of 275 gallons of freon.

- Vapor is lost from the distillation system when a holding tank is filled or drained and through vapor-relief valves that remain open on the tanks. During the filling cycle, vapor is forced out through a valve at the top of the tank. The tanks are drained by pressurizing the vessel with nitrogen gas to 30 psig to force the liquid out. Once the liquid has been drained, the gas is vented to repeat the cycle. Gases vented during filling and released during draining are assumed to be saturated with freon. This assumption may overestimate the amount of freon lost during the gas release because time spent draining the tank and bleeding off the pressure is probably inadequate for the equilibrium vapor pressure to be attained. However, the approximation is presumed to be reasonably accurate.

- Carbon Adsorption (CA) System. CA system data were obtained from PSL personnel. These included information about the frequency of regeneration of the carbon beds and the quantity of freon recovered from regeneration.

- Cleaning Operations. Solvent use data for the various work areas were gathered through detailed interviews with personnel and technicians responsible for handling solvents.

- Physical Science Laboratory Reports. Staff from PSL had previously conducted studies on particular work areas in Building 4. These studies determined the types of equipment used, venting arrangements, estimated solvent flow rates, and solvent-handling procedures within each of these work areas. Information utilized for the solvent mass balance included reports on the operations of clean rooms 7 and 12, and the refurbishing area (rooms 41S6, 41S6A, 41R9, and 41R9A).

- Facility Wastewater - Solvent concentrations measured in the facility wastewater during March, April, and November 1987 were used. These data are important in determining whether the wastewater is a source of solvent losses. These analyses did not include flow rates, nor were they performed on Building 4 wastewater exclusively.

2. Assessment of Mass Balance Data Quality

For the most part, the data sources used in this study were reliable. In some instances, information from one area corroborated data from a different source. However, some data obtained through worker surveys were known to be inaccurate. A margin of error was estimated for information that was deemed questionable.

- Purchase, Issue, and Manifest Data. As discussed in Section III, data from purchase logs for freon and TCA and the manifested waste data are considered accurate. Issue data for TCA are also reasonably accurate. Issue data for freon were not available because freon is piped directly from outside holding tanks to a holding tank (located near the distillation systems), from which it is piped to the work areas. For the purposes of this study, purchase data are assumed to be reasonable surrogates for issue data.

- Distillation System. The distillation system operating data were gathered from daily records maintained by the system operators. These data are considered accurate.

- Cleaning Operations. The quality of data gathered during the room-by-room solvent usage survey varies. Some data from the survey produced detailed information about solvent usages, while other data were less-descriptive. No overall judgment can be made regarding this information; data quality can be assessed on only a case-by-case basis. About half of the personnel interviewed provided quantitative estimates of the solvent throughput or evaporation rates of their respective areas, while the others gave qualitative or no information. When limited information was provided, general assumptions and engineering judgment were used. Every piece of equipment has an evaporative rate specific to its operation. Evaporative rates, expressed as a percentage of the solvent throughput per unit time for the particular equipment, are used to determine the evaporative losses from the equipment. The assumptions for each operation outlined below are based on results from the PSL reports:

  (1) Spray booths have an average evaporative loss of 75 percent to 100 percent. Whenever a rate could not be estimated, the value of 75 percent was assumed.

  (2) Vapor degreasers have an average evaporative loss of 10 percent.

  (3) Ultrasonic baths have an average evaporative loss of 30 percent

  (4) Unless otherwise indicated by an operator or a PSL report, bench-top operations (brushing, wiping) are assumed for all 100-percent evaporation rates.

  (5) Such operations as solvent flushing do not have typical evaporative loss rates. For each of these operations, a specific evaporation rate was estimated from information from PSL.

The work year is assumed to comprise working days of 8 hours. If the room-by-room survey specified a second or third work shift, the work year was adjusted accordingly.

- PSL Reports. The work area survey reports produced by PSL are quantitative. These reports contain information about clean rooms 7 and 12 and the refurbishing area. The reports also provide data required to perform mass balances on such equipment operations of interest as solvent usage and evaporation rates typical of cleaning equipment. Usage rates observed during the study are assumed to be representative of average usage rates thoughout the one-year duration of the mass-balance study. The data contained in each PSL report are assumed to be accurate for the duration of that particular study.

3. Mass Balance Analytical Procedures

The analytical treatment of purchase, issue, and disposal data is presented in Section III. Most of the mass balance calculations determine the solvent thoughput of the facility and estimate the quantity of solvent lost due to evaporation during equipment usage.

a. Work Area Evaporative Loss Calculations

The largest impact on the mass balance results comes from the assumptions about operating characteristics in the cleaning work areas.

The following is typical of the calculations used to determine annual evaporative losses. For a spray booth using an estimated average throughput of freon per week,

$$[TP][\rho][t][f] = E$$

where TP = Solvent throughput (gallons/week)
ρ = Solvent density (pounds/gallon)
t = Time (52 weeks)
f = Fraction evaporated,and
E = Pounds of solvent evaporated per year

When solvent throughput data are not available, the throughput can be calculated from <u>Rw</u>, the rate of accumulation of liquid waste, and the fraction evaporated:

$$\frac{Rw}{1-f} = TP$$

Representative calculations are illustrated in Appendix A.

b. Distillation System

The objective of the freon distillation system calculations is to determine the quantity of freon recycled. For any given period of time, the total quantity of purified solvent that passes through the quality control tank represents the amount of freon recycled. The solvent vapor lost during draining and filling of the distillation system tanks was calculated as twice the product of the annual volume put through the QC tank times the number of tanks in the system. This represents one throughput vapor volume lost while filling the tanks and one volume lost while draining them.

After the inventory data had been gathered at Newark AFB and processed, it was learned that significant quantities of freon vapor were lost through open pressure relief valves connecting holding tanks to the CA exhaust duct. Because this information arrived after the mass balances had been calculated, losses by this mechanism were not included in the inventory. A qualitative analysis reveals that the quantity due to this mechanism is significant - perhaps 64,000 pounds or more annually.

A qualitative estimate may be based on the fact that the CA bed became saturated in less than one day when the valves were constantly open, whereas the CA bed became saturated approximately every second day when, to the extent possible, the valves were kept closed. Vapor will be lost through an open valve, regardless of the flows or level of solvent in the tanks, as long as any solvent is present. This is due to the aspiration effect on the freon vapor in the tank caused by air flow through the CA duct. One reason this loss mechanism is so significant is that the exhaust fan drawing vapor through the CA bed operates 24 hours a day, 365 days a year, so vapor emission occurs continuously.

c. Carbon Adsorption System Calculations

Solvent recovery by the CA system was not analytically treated because the carbon beds were seldom regenerated (approximately annually). Thus, all of the vapor vented to the CA beds in the time period studied was considered lost.

The following equation may be used to estimate the quantity of freon that could be recovered for a given time period and CA bed regeneration frequency:

$$YR = [DR][F][P][\rho]$$

where YR = Pounds of freon recovered in the year studied
DR = Amount recovered (gallons) per average regeneration
F = Frequency of regeneration/period of time (e.g., week)
P = Periods/year
ρ = Density (pounds/gallon)

d. Diffusion and Convection

The last mechanism considered for vapor losses is diffusion and convection of solvents from storage and waste containers. Details of the calculations involved are in Appendix A. Briefly, a reference mass flux (0.075 lbs/hr-ft^2) was assumed for both freon and TCA. This flux was multiplied by the estimated total area of openings in the drums to determine the number of pounds of solvent lost per hour. To determine the total mass of solvent lost through diffusion, the loss rate was multiplied by the number of hours in the period studied . The mass lost to convection was simply assumed to be four times the amount lost by diffusion. This method of estimation is based on studies of vapor degreasers and is probably conservative for the losses from waste storage drums. While the assumptions used to determine diffusive and convective losses are not rigorous, they do allow an order-of-magnitude estimate of the amount of solvent lost through this mechanism.

4. Reliability of Mass Balance Results

The purchase, issue, and disposal data discussed in Section III are considered accurate. Thus the estimates of the masses of solvent going into and out of Building 4 are considered accurate.

The operating conditions of the CA and distillation systems are precisely known, so the results of calculations based on data from these sources are considered reliable. Each of the two CA systems produces approximately 18 gallons of freon when regenerated. Thus, the assumption that the CA systems were not regenerated during the year studied, results in a maximum error of about 36 gallons of freon for the one-year period.

The greatest sources of uncertainty in this study stem from the estimates of solvent usage in the individual work areas and from solvent evaporation rates particular to the equipment. In some cases, use rates were determined from data gathered during the room-by-room survey. In other cases, work station use rates were back-calculated using waste solvent generation data and an estimated evaporation rate. In still other cases, use rates were determined by multiplying an estimated equipment daily use time by an estimated percentage actual spray time. Uncertainty in the usage rates also creates uncertainty in the estimate of the quantity of solvent lost by evaporation.

SECTION III

RESULTS AND DISCUSSION

A. CHEMICAL INVENTORY SURVEY (CIS)

From 19 April 1987 until 19 April 1988, chemical usage was analyzed at Newark AFB. Sixteen different solvents were identified, which account for virtually all the solvents used in the areas of interest during the period studied. These solvents were divided into three categories based on quantity used. Two solvents were considered to be of major use, two of intermediate use, and 12 of minor use. The results are summarized in Table 2, which includes available chemical inventory data specifying purchase, issue, point of use, and disposal.

Monthly issue data were available only for November and December of 1987 and January, March, April, May, and June of 1988. As the period of interest is April 1987 to April 1988, the issue data from May and June 1988 were used only to identify likely use points and not quantities. The monthly issue data do not cover the entire time period studied; therefore, point-of-use data may not be inclusive.

The two solvents used most frequently at Newark AFB are freon and TCA. For these two solvents, purchase and waste disposal data indicate that usage and disposal rates have remained relatively constant over a 34-month period (September 1985 to July 1988) for freon and a 16-month period (February 1987 to May 1988) for TCA. Figures 4 and 5 show cumulative solvent purchase and manifest data plotted versus time (in pounds of pure solvent).

As usage rate data for TCA were not available, issue data from the N82 report were used to determine the TCA usage rate. As issue data for freon were not available, a freon usage rate was determined from purchase data by calculating an average monthly freon purchase rate from Figure 4. This rate was multiplied by 12 months (49,662 pounds/month x 12 months) to estimate the annual freon usage (or issue) rate. Because variations in the quantity stored must be considered, it would have been unrealistic and simplistic to expect the quantity of freon purchased between 19 April 1987 and 19 April 1988 to equal the quantity of freon issued and used.

The purchase and waste data were submitted to least-squares regression analysis to determine the best straight line through each set of data. The regression results are summarized in Table 3. The scatter of the data is seen qualitatively as the distance from the data points to the straight line obtained through the least-squares fit. Inspection reveals little scatter in Figure 4. The term r^2 in Table 3 is a quantitative measure of data scatter; the closer the value of r^2 to 1, the less scatter.

The slopes of the plotted data (and the X coefficient in the regression analysis) represent the average monthly rates of solvent purchase and solvent disposal. For freon, the purchase rate is 49,662 pounds/month and the disposal rate is 3,380.24 pounds/month. Dividing the former by the latter produces the ratio of solvent purchased to solvent disposed. For freon, this ratio is 14.7. When the slope of the cumulative waste line is multiplied by this rate, the purchase and disposal data plot as parallel lines, is shown in

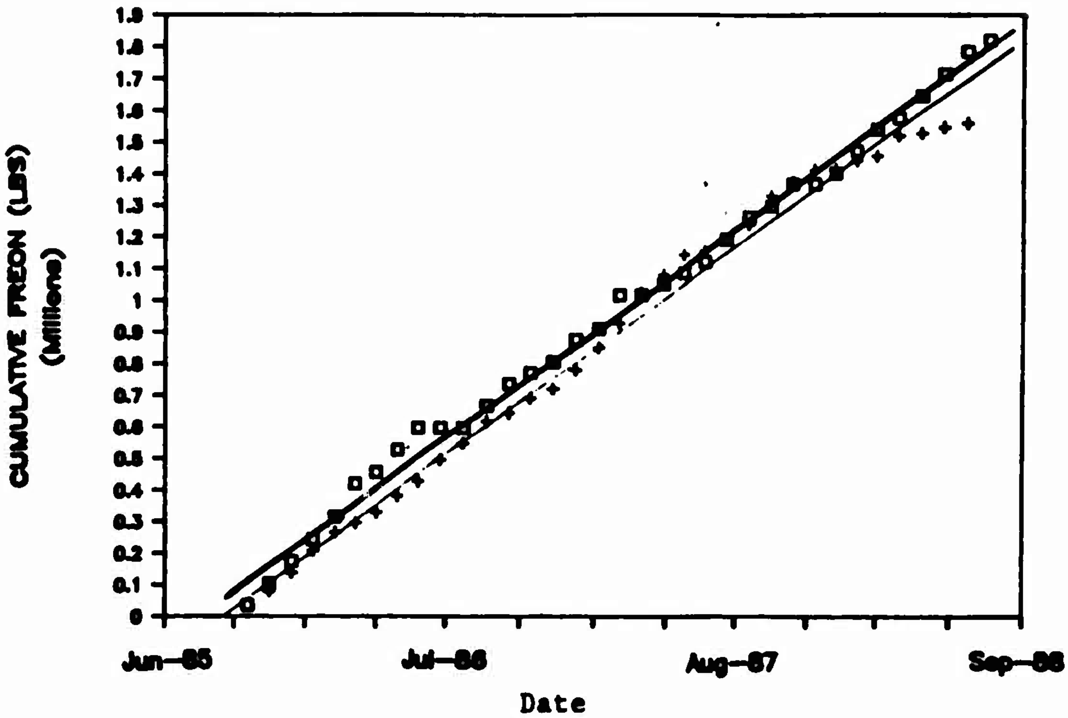
TABLE 2. SUMMARY OF CHEMICAL INVENTORY SURVEY RESULTS (19 APRIL 1987 TO 19 APRIL 1988)

Use Level	Solvent	Quantity Purchased	Quantity Issued	Location(s) of Solvent Usage	Quantity Manifested For Disposal
Major use	Freon™ 113	559,991 lbs	596,000 lbs[a]	Clean Rooms 2, 3, 4, 7, 8, 10, 11, 12, 15, 16; Refurbishing Area; Rooms 41A15, 41A32, 41H22, 41H25, 41L13, 41L20, 41L24, 41M24, 41P25	40,600 lbs
	TCA	137,395 lbs	123,000 lbs	Clean Rooms 3, 4, 7, 10, 11, 12, 15; Refurbishing Area; Rooms 41A15, 41C15, 41H25	81,600 lbs
Intermediate Use	Isopropyl alcohol (IPA)	1,375 gal	1,635 gal	Clean Rooms 2, 3, 4, 5, 8, 10, 16, Rooms: 41J25, 41A15, 41A17, 41L24, 41P25, 41L13, 41M24	641 gal
	Acetone	1,320 gal	1,397 gal	Clean Rooms 2, 3, 5, 8, 9, 10, 11, 16, Rooms: 41J25, 41H25, 41L20	722 gal
Minor Use	Toluene	180 gal	296 gal	Rooms 41L17, 41A36, 41L24, 41J23, 413SP	178 gal
	Naphtha	?	76 gal	Rooms 41A26, 41H39, 41J23, 41K30	?

[a]Quantity of virgin solvent issued

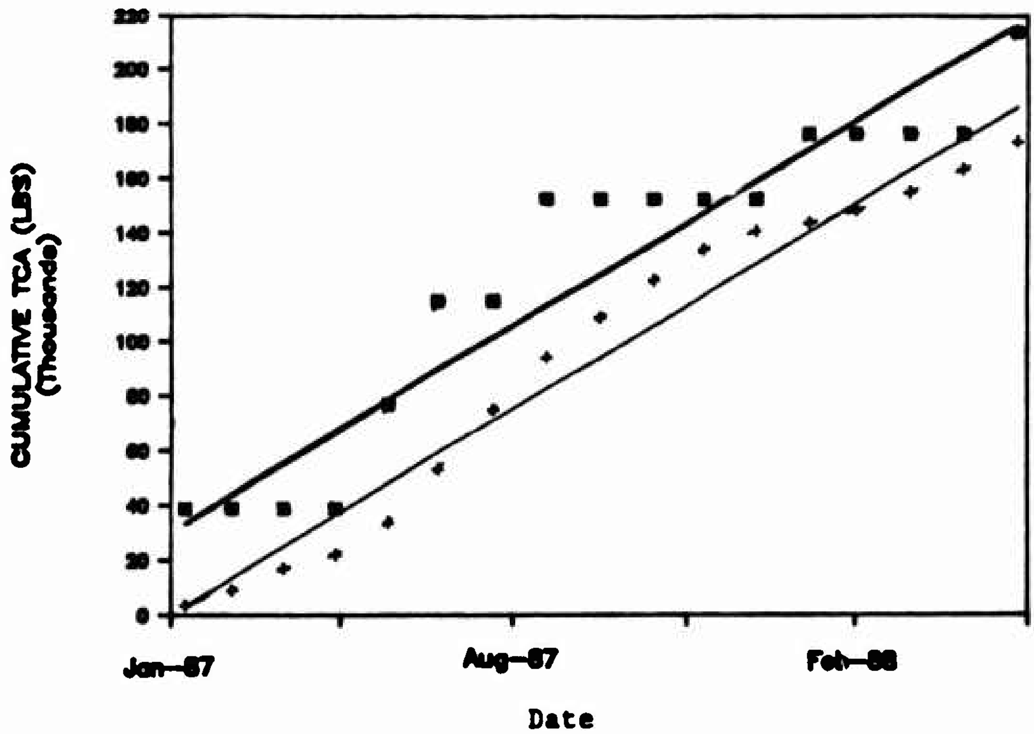
TABLE 2. SUMMARY OF CHEMICAL INVENTORY SURVEY RESULTS (19 APRIL 1987 TO 19 APRIL 1988) (CONCLUDED)

Use Level	Solvent	Quantity Purchased	Quantity Issued	Location(s) of Solvent Usage	Quantity Manifested For Disposal
Minor use	Stoddard solvent	?	55 gal	?	?
	Nontechnical grade solvents	?	49 gal	Rooms: 41A36, 41J23, 41Q35, 41M2	?
	MEK	?	43 gal	Rooms: 41H39, 41K30	?
	Methanol	0 gal	33 gal	?	?
	Hexane	?	33 gal	Rooms: 41H39, 41E21, 41A26	?
	Methylene chloride	?	31 gal	Rooms: 41C6, 41H39	?
	Denatured alcohol	?	3 gal	?	?
	Xylene	?	2 gal	Room: 41E21	?
	Butanol	?	<1 gal	?	?
	Miscellaneous solvents (paint and epoxy strippers, thinners)		<1 gal	Various rooms	?



□ Cumulative freon purchases + Cumulative freon disposed x 14.7

Figure 4. Least-Squares Fits to Freon Purchase and Disposal Data



□ Cumulative TCA purchases + Cumulative TCA disposed x 1.66

Figure 5. Least-Squares Fits to TCA Purchase and Disposal Data

Figure 4. Similarly, for TCA data, the ratio of purchase rate (11,408 pounds/month) to disposal rate (6,883 pounds month) produces a ratio of 2.66 as indicated in Figure 5. The reciprocal of this ratio is the fraction of solvent purchased that is eventually manifested for disposal.

TABLE 3. LINEAR REGRESSION RESULTS FOR SOLVENTS PURCHASED AND DISPOSED

Parameter of Regression Output	Purchased		Disposed	
	Freon	TCA	Freon	TCA
r^2	0.994998	0.910303	0.989391	0.967826
Constant	62128.77	22005.77	581.37	-5213.81
Standard Error of Y	37637.13	19706.04	3539.65	6905.82
Number of Observations	36	18	34	18
Degrees of Freedom	34	16	32	16
X Coefficient	49662.31	11408.22	3380.24	6883.03
Standard Error of Coefficient	603.84	895.27	61.88	313.74

These plots indicate offsite disposal of approximately 6.8 percent [(1/14.7) x 100] of the freon and 60 percent [(1/1.66) x 100] of the TCA used. The results of the regression analyses also indicate that solvent purchase and disposal rates were reasonably constant over the 1-year period studied.

B. SOLVENT MASS BALANCE

The solvent mass balance at Newark AFB focused on freon and TCA usage from April 1987 to April 1988. These two solvents comprised more than 94 percent of the total quantity of solvents used at Newark AFB during the period studied. For both solvents, the overall mass balance results are presented, followed by a breakdown of where losses occurred and a discussion of these losses.

1. Freon Mass Balance Results

a. Summary of Results

The results from an analysis of freon purchase and distillation system operation data indicate that 2.32 million pounds of freon was used in the facility during the 1-year period studied. Calculations based on freon purchase data indicate that 555,000 pounds of freon (596,000 pounds used minus 40,600 pounds manifested for disposal) was lost, which comprised 24 percent of the freon used at the facility during the 12 months of this study. As the 40,600 pounds manifested for disposal is accounted for, the 555,000 pounds of unrecovered (and unaccounted for) freon is the net freon lost.

The results of an analysis of the room-by-room survey information and PSL reports indicate a throughput of only 1.82 million pounds. Based on these data sources and distillation system data, 427,000 pounds of lost freon can be accounted for. Although these losses and solvent throughput rates are less than what the balance based on purchase and still operation indicates, the ratio of the accounted freon losses (427,000 pounds) to the accounted throughput (1.82 million pounds) is 23.5 percent. This ratio is close to the 24.0-percent ratio obtained from purchase and manifest data described above. These results indicate that the throughput estimates based on worker surveys

and PSL reports is low, (1.82 million pounds were estimated from worker surveys, 2.32 million pounds were calculated from freon purchase and distillation system operation data); however, the evaporation rate estimates and calculations are accurate.

Table 4 summarizes the mass balance results, and the distribution of unrecovered freon is shown in Table 5. The losses are presented as percentages in descending order of the total accounted freon lost. The sources of the accounted losses are the process operations, distillation system operations, and a few miscellaneous sources. Each of these losses is discussed in detail in the following sections. Although manifested waste is not actually a solvent loss (because it is recovered), it is also discussed in this section.

b. Discussion of Solvent Fate

The solvent losses in this section are based on the analysis of the room-by-room survey results and the PSL reports.

(1) Process Operations Losses

The solvent losses from the various cleaning operations conducted in Building 4 are referred to as operational losses in this report. These operations include all of the first-floor rooms that involve the use of freon or TCA.

A study of the fate of freon showed that 76 percent of the accountable losses were due to these operations. A summary of the particular operations and attributable losses is presented in Table 6. The process operations were grouped as spray booths and flush units, vapor degreasers, ultrasonic baths, and brushing, wiping and miscellaneous. Process operation losses result from evaporation during use of the cleaning equipment. The quantity of freon lost due to evaporation from spray and flush operations was 236,000 pounds or 72 percent of the process operation losses. Losses from these operations are high for a variety of reasons, including the volatility of freon, the generally fine spray of the solvent, the exposure to a constant airstream, and the geometry of the booths in which the operations are housed. High evaporative losses (75-100 percent) are typical of spray and flushing booths. Other operational losses were due to ultrasonic cleaners (21 percent), degreasers (4.3 percent), and brushing or miscellaneous operations (1.7 percent). Assumptions made in defining the operating parameters are outlined in Section II.

An important consideration about the operational evaporative losses is the destination of the vapors. Ideally, all of the vapors should be directed to a recovery and recycling system that operates with an efficiency of 100 percent. However, many of the process streams at Newark AFB are vented to the atmosphere rather than to a recovery system, and some sources are not directly vented at all. The vapor streams are grouped into three categories by where they are vented: to a solvent-recovery carbon-adsorption unit, to the atmosphere, and to ambient air in the process rooms. These categories are discussed in more detail below.

TABLE 4. FREON MASS BALANCE RESULTS

Parameter	Data Source	Quantity (lbs/yr)	Percent of Total Quantity Issued (percent)
Quantity of freon used	Purchase and distillation system logs	2,320,000	100
Quantity of freon recycled	Distillation system logs	1,720,000	74
Quantity of freon lost		596,000*	26
Quantity of freon manifested	Waste manifest logs	40,600	2
Total quantity of unrecovered freon	The quantity of freon issued minus the quantity of freon manifested	555,000*	24

* These values have been rounded of to the nearest 1,000 pounds

TABLE 5. DISTRIBUTION OF UNRECOVERED FREON

Parameter	Quantity (lbs/yr)	Percent of total unrecovered freon
Total unrecovered freon	555,000	100
Quantity of freon accountable by mass balance	427,000*	77
		Percent of Accountable Unrecovered freon
Process operational losses:	326,400	76
Distillation system operational losses	94,700	22
Other	6,270	2
Total (accountable unrecovered losses)	427,000*	100

*These values have been rounded off to the nearest 1,000 pounds

TABLE 6. SOURCE BREAKDOWN OF EVAPORATIVE FREON LOSSES LOSSES FROM PROCESS OPERATIONS

Operation	Quantity (lbs)	Percentage of Total Accounted Freon
Spraying/flushing booths	238,000	73
Ultrasonic cleaners	68,600	21
Degreasers	13,900	4.3
Brushing/wiping and miscellaneous	5.900	1.7
Total	326,400	100

a. Vapor Streams to the CA Units and Outside the Building

The vapor generated from the spray and flushing operations is drawn out of the process booth by vented hoods. Although some ultrasonic baths and degreasers also contribute vapors to these hoods, the quantities are comparatively small and not considered in this discussion.

The exhaust from the hoods is directed either to the CA bed or to the atmosphere. Of the 19 solvent-use areas, at least nine had one vapor exhaust hood leading to a CA bed. The remaining 10 had vapor exhaust hoods venting outside the building. It was found that only 33 percent (109,000 pounds) of the accounted vapor lost during process operations was vented to the CA bed. The remaining 67 percent (217,000 pounds) was vented directly to the outside air.

Of all the cleaning operations at Newark AFB, the flushing station in the refurbishing area uses the most freon in its operation and is the largest vapor producer (approximately 100,000 pounds per year). Solvent substitutes or revised operating procedures for the solvent usages in these two areas are being researched and implemented. The flushing stations will presumably cease using significant quantities of freon or TCA upon eventual implementation of new solvents and operating procedures.

b. Vapor Streams to Ambient Room Air

The ambient air surrounding a work station receives vapor emissions from degreasers, ultrasonic bath and bench-top areas. Assumptions about evaporative losses from these operations are outlined in Section III.B. The combined vapor losses from these operations comprise 27 percent (88,400 pounds) of the accounted freon process operation losses. The vapor from these sources is exhausted through the general room ventilation systems.

The ultrasonic baths contribute the most vapor to the ambient air (68,600 pounds). Most of the baths are located in clean rooms 3 and 7. Degreasers have evaporative losses of 13,900 pounds and are widely distributed throughout all work areas and clean rooms. Benchtop sources contribute 5,900 pounds of evaporative losses and are also widespread throughout the work areas and clean rooms.

(2) Distillation System Operation Losses

Freon losses from the distillation system account for 22 percent (94,700 pounds) of the 427,000 pounds of accountable lost freon. The distillation system includes a series of tanks through which recycled freon passes. These tanks are filled and drained frequently during still operations. As a tank is filled, vapor is pushed out a valve and into the duct leading to a CA unit. Vapor loss calculations were based on the assumption that the freon vapor pressure is maintained at 334 mm Hg during the ventings and that each venting releases exactly 1 tank volume of vapor. Typically, a given volume of freon passes through six such tanks during the distillation process.

After the data-gathering efforts at Newark AFB were concluded, the tank-venting and valve-setting practices were changed to minimize the amount of vapor released to the CA bed. The valves connecting the holding tanks to the venting duct had been left open. Airflow in the venting duct created a pressure drop at the valve, causing freon vapors to be constantly drawn from the tanks. The losses by this mechanism were not calculated as part of this inventory because the information was furnished too late. A qualitative analysis reveals that the quantity lost due to this mechanism is significant, perhaps exceeding 64,000 pounds per year. This loss mechanism is discussed in more depth in Section II.

These changes will result in a noticeable load reduction to the CA unit. PSL personnel will continue to experiment with different operational practices to further decrease freon vapor losses.

(3) Other Losses

The annual loss of liquid freon is not significant. Losses of liquid result from work area spills or improper solvent disposal in the central vacuum system. Recorded events amounted to only 331 pounds in the period studied. Data pertaining to losses in the vacuum system were not available, although the room-by-room survey indicates that these losses were small.

Other freon losses comprise less than 2 percent of the total losses accounted for in the mass balance. These sources include convective and diffusional losses from openings in waste drums and sumps, vapor losses from filling waste cans and drums, and losses from filling bulk freon storage tanks. Diffusional losses are small compared to convective losses. Calculations of these losses are outlined in Appendix A.

Vapor losses were estimated by applying a solvent flux to a total area available for vapor diffusion. Each of the solvent recovery drums and some of the sump pumps have a small opening, usually about 2 to 4 square inches, from which vapor escapes. The total amount of diffusional freon loss

was multiplied by a factor of 4 to account for convectional losses. The final estimated losses were less than 2 percent of the accounted losses.

(4) Manifested Freon Waste

During this study, the amount of freon manifested and shipped offsite as waste was 40,600 pounds. This is the cumulative sum of the freon in all of the 55-gallon drums that were manifested as waste and analyzed by PSL. This sum accounts for 6.8 percent of the quantity of freon used (696,000 pounds) in the year studied. This liquid freon waste is not recycled by distillation because it is contaminated by other solvents.

2. TCA Solvent Mass Balance Results

The TCA issue data show that 123,000 pounds were issued (used) during the 1-year period studied. Of this amount, 66 percent (81,600 pounds) was manifested as liquid waste. This indicates an evaporative loss of 34 percent (41,400 pounds) for the period studied. The results from the room-by-room survey indicate that the TCA throughput was 200,000 pounds, of which 122,000 pounds was lost by evaporation. TCA usage is summarized in Table 7. TCA is lost as manifested liquid waste and, in operations, by evaporation, convection, diffusion, and vapor emissions from tanks and drums during filling and draining operations.

An analysis of the room-by-room survey data indicates that both TCA evaporative loss estimates and solvent throughput estimates are exaggerated. The survey results showed evaporative losses of 122,000 pounds of TCA out of 200,000 pounds throughput (62 percent), which is much higher than the 31 percent evaporative losses predicted by the purchase, issue, and waste manifest data. Because the majority of the TCA evaporative losses come from just two areas, an excessive estimate for one or both of these areas would significantly affect the TCA mass balance results.

Estimates of TCA usage and evaporation were based on the results from room-by-room surveys of Newark personnel and on PSL reports. As purchase and issue data are well documented, the estimated survey throughput amount of 200,000 pounds is considered excessive. This estimate was based only on the best judgment of the operators; most of the solvent usage rates for operations using TCA in quantity are unknown because the supply pipes are not equipped with flowmeters or totalizers.

The main sources of TCA evaporative losses are two primary work areas, clean room 12 and the refurbishing area (which comprises rooms 41S6 and 41S6A). The results of the room-by-room survey indicate that these two areas contributed more than 90 percent of the TCA evaporative losses. Flushing operations in room 41S6 contributed 33 percent of the total TCA evaporative losses. The single largest loss was from spray operations in clean room 12, which generated over 50 percent of the total TCA evaporative losses. Table 8 summarizes the accounted losses of TCA from operational sources. As shown in the table, 98.2 percent of the losses can be attributed to spray and flush operations alone.

TABLE 7. TCA USAGE RESULTS

Parameter	Data Source	Quantity* (lbs/yr)	Percent of Total Quantity Issued (percent)
Quantity of TCA manifested	Waste manifest logs	81,000	66
Quantity of TCA not recovered	Based on difference	42,000	34
Quantity of TCA issued	Issue data	123,000	100
Estimated throughput rate	Room survey results	200,000	160
Estimated unrecovered volume	Room survey results	112,000	91

*These values have been rounded to the nearest 1,000 pounds/year

TABLE 8. SOURCE BREAKDOWN OF TCA EVAPORATIVE LOSSES FROM WORK AREA OPERATIONS

Operation	Quantity (lbs)	Percent of total accounted TCA
Spraying/flushing booths	109,000	98.2
Brushing/wiping/miscellaneous operations	1,023	0.9
Degreasers	498	0.5
Ultrasonic cleaners	402	0.4

SECTION IV

SENSITIVITY ANALYSIS

The purpose of a sensitivity analysis is to investigate what effect changes in the underlying assumptions made in an analysis will have on the results. The sensitivity analysis is performed by adjusting the assumptions by a certain percentage and repeating the calculations based on the new assumptions. The new results can then be compared with the old results to determine what effect the change in assumptions causes. This analysis will focus on freon because it is the most important solvent used at at Newark AFB in terms of both quantity and environmental concern. The goal of this sensitivity analysis is to determine the validity of the results from the mass balance, given the uncertainties inherent in the assumptions.

As summarized in Tables 4 and 5, there are three primary sources (operational losses, distillation system losses, and manifested waste) of freon losses. The quantity estimated from each of these sources is affected by specific assumptions made for the particular source. Operational losses account for approximately 80 percent of the total accounted freon losses. The two key assumptions for this source are the throughput in each area and the rates of evaporation from the various types of equipment.

Freon losses from the distillation system account for about 20 percent of the total. The key assumptions for this source are the throughput and the concentration of freon present in the released vapor.

Manifested waste freon accounts for less than 10 percent of the total quantity of freon lost. Because each load of manifested waste was analyzed to determine its composition, the only assumptions involved in this figure concern the quantity of solvents in each drum and the actual number of drums shipped offsite in a 1-year period. Because the information from these sources is considered accurate, the manifested waste assumptions will not be varied in this analysis.

A miscellaneous category termed other losses, accounts for 1 percent of the remaining total losses. Other losses include diffusional and convective losses as well as losses occurring during the filling of waste drums. There were a number of underlying assumptions used in developing this quantity; however, because it represents such a small fraction of the total, other losses will not be varied in this sensitivity analysis.

To determine the impact that changes in the underlying assumptions have on the overall mass balance, some benchmark is necessary for comparison. As discussed in Section III, the estimated overall throughput (calculated primarily from worker surveys) totaled 1,819,000 pounds and was 78.5 percent of the expected total throughput of 2,316,000 pounds (calculated based on purchase and distillation system recovery data). Calculated losses totaled 468,000 pounds (calculated from process operation, distillation operation, other, and manifested losses), which is 78.5 percent of the expected losses of 596,000 pounds (based on purchase data).

The benchmark against which the effect that varying assumptions exert on the results will be measured is the ratio of the estimated overall throughput to the expected total throughput. As mentioned above, this ratio is 78.5 percent. For the purpose of this sensitivity analysis, this benchmark ratio will be referred to as the throughput percent closure (TPPC).

As discussed in Section III, manifest data are considered accurate, and changes in these quantities due to changes in the underlying assumptions are, for the purpose of this analysis, considered negligible. Other losses represent such a small fraction of the the total losses that changes in their underlying assumptions will produce only very small changes in the overall results. The sum of these two categories (manifested losses and other losses) can be subtracted from the expected total losses of 596,000 pounds to yield 549,000 pounds. This figure is the reference quantity against which the effects of changes in underlying assumptions can be measured. The sum of the losses from the two remaining categories, process and distillation system operation losses, is about 421,000 pounds (76.7 percent of the benchmark quantity). For the remainder of the sensitivity analysis, this value of 421,000 pounds will be referred to as total freon lost, and the 76.7 percent benchmark as total freon lost percent closure (TFLPC).

A. SENSITIVITY OF RESULTS OBTAINED FOR FOUR PRINCIPAL AREAS

Of the 326,000 pounds of process operation losses, 208,000 pounds (64 percent) can be attributed to clean rooms 12 and 3 and the refurbishing area. In addition, distillation system operations losses comprise 22.5 percent of the total accountable freon losses. For this reason, the sensitivity analysis will focus on these four areas.

1. Clean Room 12

Increasing the throughput in clean room 12 by 10 percent while holding assumed evaporation rates constant increases the estimated overall throughput by 112,600 pounds and the amount of freon lost by 4,500 pounds. The TPPC increases from 78.5 to 83.4 percent. The total freon loss increases from 421,000 pounds to 425,500 pounds (1.1 percent). The TFLPC also increases from 76.7 to 77.5 percent. This indicates that for every 1-percent change in the throughput assumed for clean room 12, overall results are increased or decreased by approximately 0.6 percent for throughput and 0.1 percent for freon lost. Most of the equipment in this area has a relatively high assumed evaporation rate (except for the sealed flushing units, which are assumed to have evaporation rates of zero). Increasing the rate for sealed units from 0 to 5 percent (while holding the throughput constant) adds 53,500 pounds to the losses. This increases the total freon loss by 12.7 percent to 474,500 pounds. The TFLPC increases from 76.7 to 86.4 percent indicating that a 1-percent change in the evaporation rate for these units will cause a 2.5-percent increase in the total freon loss.

2. Refurbishing Area

In the refurbishing area, increasing the throughput by 10 percent at a constant evaporation rate increases the estimated overall throughput by 24,700 pounds (up 1.4 percent) and the total freon loss to 433,000 pounds, a rise of 2.9 percent. This, in turn, increases the TPPC from 78.6 to 79.6 percent and the TFLPC from 76.7 to 78.9 percent. Thus, a 1-percent change in throughput in clean room 3 will cause a 0.14-percent change in the throughput and a 0.29-percent change in the freon loss. The pieces of equipment in the refurbishing area using the largest quantities of freon are the flushing units. If the assumed evaporation rate is increased from 50 percent to 55 percent, the total freon loss increased to 432,000 pounds. This increment constitutes a 2.5-percent increase in total freon loss, and an increase of the TFLPC from 76.7 percent to 78.6 percent. Thus, each 1-percent change in the evaporation rate from the flushing units causes a 0.5-percent change in the freon loss.

3. Clean room 3

Increasing the throughput in clean room 3 by 10 percent adds 15,000 pounds to the throughput and 4,200 pounds to the total freon loss, increases of 0.8 and 1 percent, respectively. This, in turn, increases the TPPC from 78.6 percent to 79.0 percent and the TFLPC from 76.7 to 77.5 percent. Thus, a 1-percent change in throughput in clean room 3 will cause a 0.08-percent change in throughput and a 0.01-percent change in freon loss. Holding the value of the throughput constant and increasing the average evaporation rate from 28 percent to 33 percent will increase the evaporative losses to 428,500 pounds, a rise of 1.8 percent. The TFLPC increases from 76.7 percent to 78.1 percent. Thus a 1-percent change in the evaporation rate will produce a 0.36-percent change in freon loss.

4. Distillation System

Two key parameters are used to determine losses from the distillation system during holding tank draining and filling operations. The first is the total volume of gas emitted. The second is the concentration of freon in the emitted gas. By making assumptions regarding these two parameters, the freon loss during tank filling and draining operations was calculated. If the concentration of freon in the vapor remains constant and the volume of vapor lost is increased by 5 percent, approximately 2,200 pounds more will be lost. This will increase the total freon loss by about 0.5 percent and the TFLPC from 76.7 to 76.9 percent. Thus, a 1-percent change in the quantity of vapor lost will change the freon loss by 0.04 percent. A 1-percent change in the assumed vapor concentration will change the total freon loss by about 1,000 pounds (0.2 percent).

A quantitative evaluation of the freon loss through tank valves left open continuously was presented in Section II. As stated, this calculation was not included in the inventory results because the information arrived after the calculations had been performed.

None of the assumptions discussed above are mutually exclusive. In other words, these changes may be cumulative. Separate and cumulative effects of varying the assumptions used in the analysis are summarized in Table 9.

Table 9. SEPARATE AND CUMULATIVE EFFECTS OF VARYING THE BASIC ASSUMPTIONS MADE IN FREON MASS BALANCE

Source	Estimated Losses	Local Throughput Increase (%)	Increases Total Throughput (%)	Increases Total Losses (%)	Average Local Increase Evaporative Rate (%)	Increases Total Losses (%)
Clean room 12	120,000	1	0.6	0.1	1	2.5
Refurbishing area	45,200	1	0.14	0.29	1	0.5
Clean room 3	42,500	1	0.08	0.01	1	0.36
Total process operation losses	326,000	1	1.0	0.78	1	4.3
Total distillation system operation losses	94,700	1	--	0.5	1	0.23
Total accounted freon losses	421,000	1	1.0	1.1	1	4.4

B. SENSITIVITY ANALYSIS RESULTS

The results of the sensitivity analysis show that, in general, changes in the underlying assumptions exert relatively small effects on the mass balance results. However, a small change in the assumed evaporation rate for the flush units in clean room 12 leads to a disproportionately large change in the overall results. When taken in the aggregate, increases or decreases in assumed throughput or evaporation rates cause a linear response in the mass balance results. That is, an across-the-board 1-percent increase in throughput causes the total estimated losses to increase by 1.1 percent. However, an equivalent increase in evaporation rates causes a 4.4-percent increase in total losses. This lower linearity in throughput response (compared with evaporation rate response) indicates that, while the magnitude of the losses may not be exact, the relative quantities from the various sources are accurate.

SECTION V

CONCLUSION AND RECOMMENDATIONS

The primary conclusion is that the most-significant sources of freon vapor losses are not connected to any type of vapor recovery system. Indeed, the results of this study indicate that although almost half of the rooms are vented to one of the two CA systems, only 33 percent (109,000 pounds) of the freon evaporating during processes passes into the beds. The 67-percent balance (217,000 pounds) is vented directly to the outside air.

Another significant source of freon vapor emissions is the carbon adsorption beds. In the period studied, all freon vapor vented to the beds was lost because the system was regenerated only once or twice, whereas the bed appeared to become saturated after a single day of operation. A major source of this vapor load is the distillation system. The existing CA system, while adequate for collecting freon vapor exhausted from process operations, cannot effectively control emissions from the distillation system as it is currently operated. To operate the CA beds efficiently, the regeneration schedule must be stepped up to at least twice per week, and the distillation holding tank operations must be altered to significantly lower the load on the CA system. (Added note: Several months after the data collection efforts at Newark were concluded, valves were placed on the open tanks to reduce vapor losses. This should significantly improve CA bed efficiency.)

APPENDIX A

MASS BALANCE

The general equation for the mass balance of freon and TCA is

Solvents in + Change in solvents stored = Solvents manifested +
Solvents evaporated +
Solvents to drain

<u>Solvents evaporated</u> includes operational evaporative losses, losses from the venting of solvent vapors, etc.

The solvent values are referenced to a specific time period; in this example, 1 year is used.

Rearranging the equation and solving for solvents evaporated gives

Solvents evaporated = Solvents in + Change in solvents stored
- Solvents manifested
- Solvents to drain

For the freon mass balance,

Solvents evaporated = 596,000 + 0 - 40,600 - 0 (pounds)
= 555,000 pounds

It is assumed that Solvents in = Quantity of freon purchased during the 1-year period.

A. SOLVENT EVAPORATIVE LOSSES FROM EQUIPMENT

The calculations of solvent loss due to evaporation from cleaning equipment are based on evaporation rates that are applied to either solvent throughput or solvent usage information. Each type of equipment, such as a spray booth or a vapor degreaser, has a solvent evaporation rate associated with its use. For a given period of time, t, the basic equation used for these calculations is

Evaporative loss (t) = Solvent throughput (t) x Evaporation rate (t)

EXAMPLE: Freon evaporative loss from an ultrasonic bath

Solvent throughput = 2 liters each day
Evaporation rate = 20 percent
Evaporative loss = 2 liters freon each day x 0.20
= 0.4 liters freon each day

or on a yearly basis,

$$0.4 \frac{\text{liter}}{\text{day}} \times \frac{1 \text{ gallon}}{3.78 \text{ liter}} \times 13.1 \frac{\text{pounds}}{\text{gallon}} \times 250 \frac{\text{days}}{\text{year}} = 347 \frac{\text{pounds freon}}{\text{year}}$$

B. SOLVENT THROUGHPUT CALCULATION

When the solvent throughput of a piece of equipment is the unknown quantity, the equation takes the form

$$\text{Solvent throughput (t)} = \frac{\text{Amount of liquid waste (t)}}{\text{1 - Evaporation rate}}$$

EXAMPLE: Throughput of a freon spray booth

Liquid waste = 5 gallons each week
Evaporation rate: = 75 percent

$$\text{Solvent throughput} = \frac{\text{5 gallons freon/week}}{1 - 0.75}$$
$$= \text{20 gallons freon each week}$$

Given a 13,000-pound/year throughput, this represents 9,800 pounds/year of evaporative losses from the spray booth.

C. DISTILLATION SYSTEM CALCULATIONS

Calculations based on distillation system data were performed to determine the total amount of freon recycled during the time study and also to calculate the solvent vapor losses that occurred when the tanks in the system were filled and drained.

Throughput Calculations of Recycle Amount

Control volume of Quality control tank = 300 gallons
Number of acceptable tank loads (April 1987 - March 1988) = 477
Average gallons per load = 275

$$\text{Recycled freon} = 275\ \frac{\text{gallons}}{\text{tank}} \times 477\ \frac{\text{tanks}}{\text{year}} \times 13.1\ \frac{\text{pounds}}{\text{gallon}} = 1{,}720{,}000\ \frac{\text{pounds}}{\text{year}}$$

Note: The recycled freon quantity does not represent the amount of freon at Newark AFB at any given time. It represents the total amount of freon that passed through the distillation system. This amount, plus the freon purchased and minus the manifested freon waste, is the total freon throughput of the facility during the year studied.

1. Vapor Calculations

The vapor calculations are needed to determine the amount of solvent in the vapor state occupying a given volume (such as a freon holding tank). This information is useful for calculating the quantity of freon lost during distillation system ventings.

The amount of solvent vapor in a given volume can be calculated from the ideal gas law:

$$\frac{\text{moles}}{\text{volume}} = \frac{\text{vapor pressure of solvent}}{\text{gas constant x temperature}}$$

For freon vapor in a tank,

Vapor pressure = 334 mm Hg = 0.439 atmospheres
Temperature = 298 K
Gas constant = 0.0821 L-atm/mol-K

$$\frac{\text{moles}}{\text{volume}} = \frac{0.439}{0.0821 \times 298} = 0.018 \frac{\text{moles}}{\text{liter}}$$

Converting this into pounds of freon per gallon of vapor gives

$$0.018 \frac{\text{mole}}{\text{liter}} \times 187.4 \frac{\text{grams}}{\text{mole}} \times \frac{1 \text{ pound}}{454 \text{ grams}} \times 3.78 \frac{\text{liters}}{\text{gallon}} = 0.028 \frac{\text{pounds}}{\text{gallon}}$$

For one 300-gallon tank,

$$300 \frac{\text{gallons}}{\text{vent}} \times 0.028 \frac{\text{pounds}}{\text{gallon}} = 8.4 \frac{\text{pounds freon}}{\text{vent}}$$

The reclaimed freon was assumed to pass through five holding tanks in the distillation system (tanks M-2, M-4, M-7, QC, and a reuse tank) and to experience two ventings each tank. Virgin freon passed through only one holding tank. The freon passing through the recycle collection tanks was assumed to displace exactly one volume of vapor. The collection tank is drained by pumping action instead of nitrogen at 30 psig, and therefore vapor is lost only while the tank is being filled.

D. CONVECTION AND DIFFUSION CALCULATIONS

Solvent vapor escapes by diffusion through openings in solvent containers. The 55-gallon waste collection drums and small solvent sump pumps are considered sources of diffusion losses.

The diffusion calculations were based on a solvent diffusion flux of 0.075 pounds/ft^2-hr (Reference: A. Graham, Electroplating Engineering, p 147, Litton Educational Publishing, Inc., 3rd edition, 1970). This rate was derived from measurements of trichloroethylene and perchloroethylene vapors, but it should be a responsible approximation for TCA and freon, which have similar structures and properties.

An average drum was assumed to have a 3-inch-diameter bung hole and a 1.5-inch-diameter tube passing through the bung. Although some of the bung holes were wrapped with a piece of aluminum foil, this was not considered to inhibit solvent diffusion or convection.

Diffusion = (open area) x (flux rate) x (time of exposure)

Number of drums = 306
Percent freon in gas = 32
Average open area = 3.9 in^2/drum
Vapor flux = 0.075 lb/ft^2-hr

$$\text{Open area} = 3.9 \frac{\text{in}^2}{\text{drum}} \times \frac{1 \text{ ft}^2}{144 \text{ in}^2} \times 306 \text{ drums} = 8.3 \text{ ft}^2$$

Time of exposure = 250 days x 24 hours/day = 6,000 hours

$$\text{Diffusion loss} = 8.3\ \text{ft}^2 \times 0.075\ \frac{\text{pounds}}{\text{hour-ft}^2} \times 6{,}000\ \text{hours} \times 0.32\ \frac{\text{parts freon}}{\text{gas mixture}}$$

$$= 1{,}200\ \text{pounds}$$

The diffusional losses were multiplied by a factor of 4 to estimate losses due to convection. Most of the drums are located in hallways or open areas, where there was moving air.

Eleven of the freon sump pumps were found to have openings in the sump cover. The average opening was approximately 5 in^2, resulting in annual losses of 172 pounds due to diffusion. The total sump pump losses due to convection and diffusion were approximately 900 pounds per year.